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Evaluation of Co-firing and Reburning Biomass Syngas in a Coal-fired Boiler

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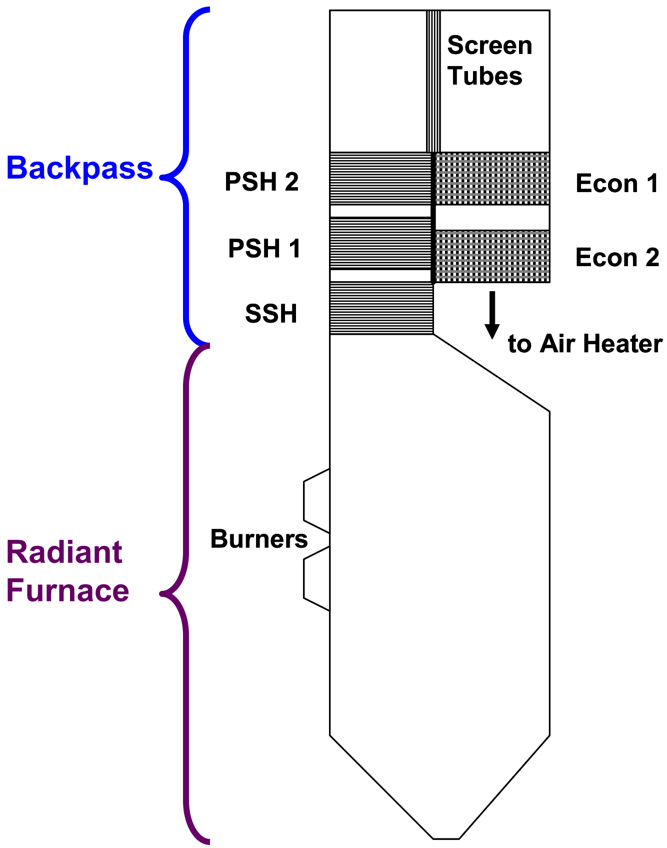
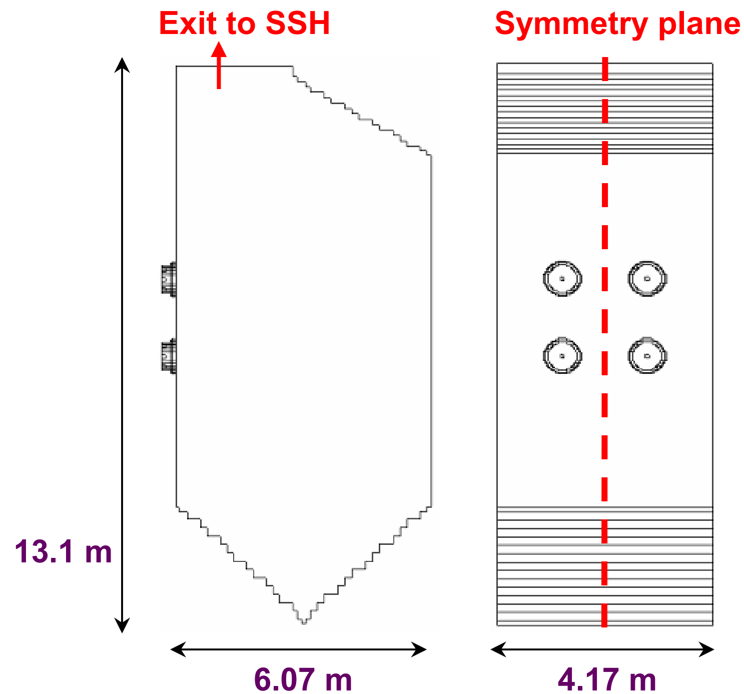
Project Objectives

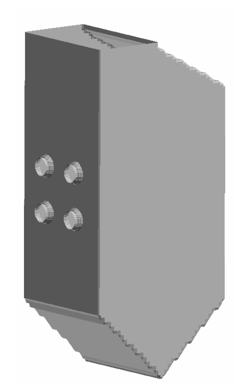
- Evaluate the feasibility of syngas utilization in a coal-fired boiler
  - Syngas from gasified paper mill rejects
- Quantify impacts of syngas co-firing and reburning on:
  - NOx, CO, LOI
  - Furnace thermal efficiency
  - Corrosion
- Provide guidance on syngas injector design / boiler operation

Furnace Design
(70 tph steam)





333,700 cells for radiant half-furnace model



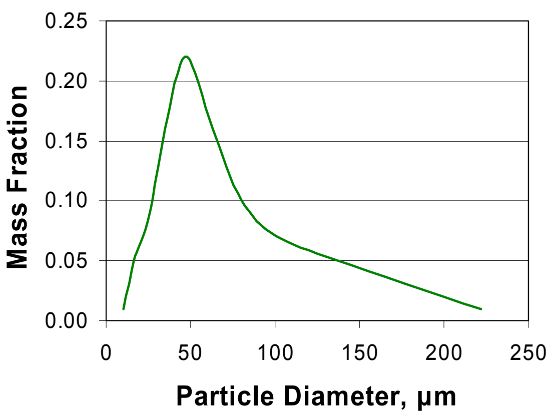
- Use separate analyses for furnace and backpass

Fuel Properties

Coal Properties

	Ping Shuo Coal wt%-as rcvd
C	65.59
H	3.95
O	7.96
N	1.2
S	0.26
Ash	12.64
Moisture	8.4
Volatile	25.62
Fixed C	53.34
HHV (BTU/lb)	11453

Particle Size Distribution



Syngas Properties

	Cases 1-4	Case 5
Moisture, %wet	22.78	21.99
N_2	46.96	49.42
H_2	7.79	6.86
CO	5.17	4.37
CO_2	11.64	12.47
CH_4	3.78	3.43
C_2H_2	0.34	0.33
C_2H_4	1.47	1.01
C_2H_6	0.031	0.023
NH_3	0.045	0.090
HCN	0.005	0.004
HHV, kcal/kg	1,247	1,085

- **Low heating value (NG = 12,872 kcal/kg)**
- **Low hydrocarbons (~5%), H_2 and CO**
- **High NH_3 and HCl**

Summary of Cases

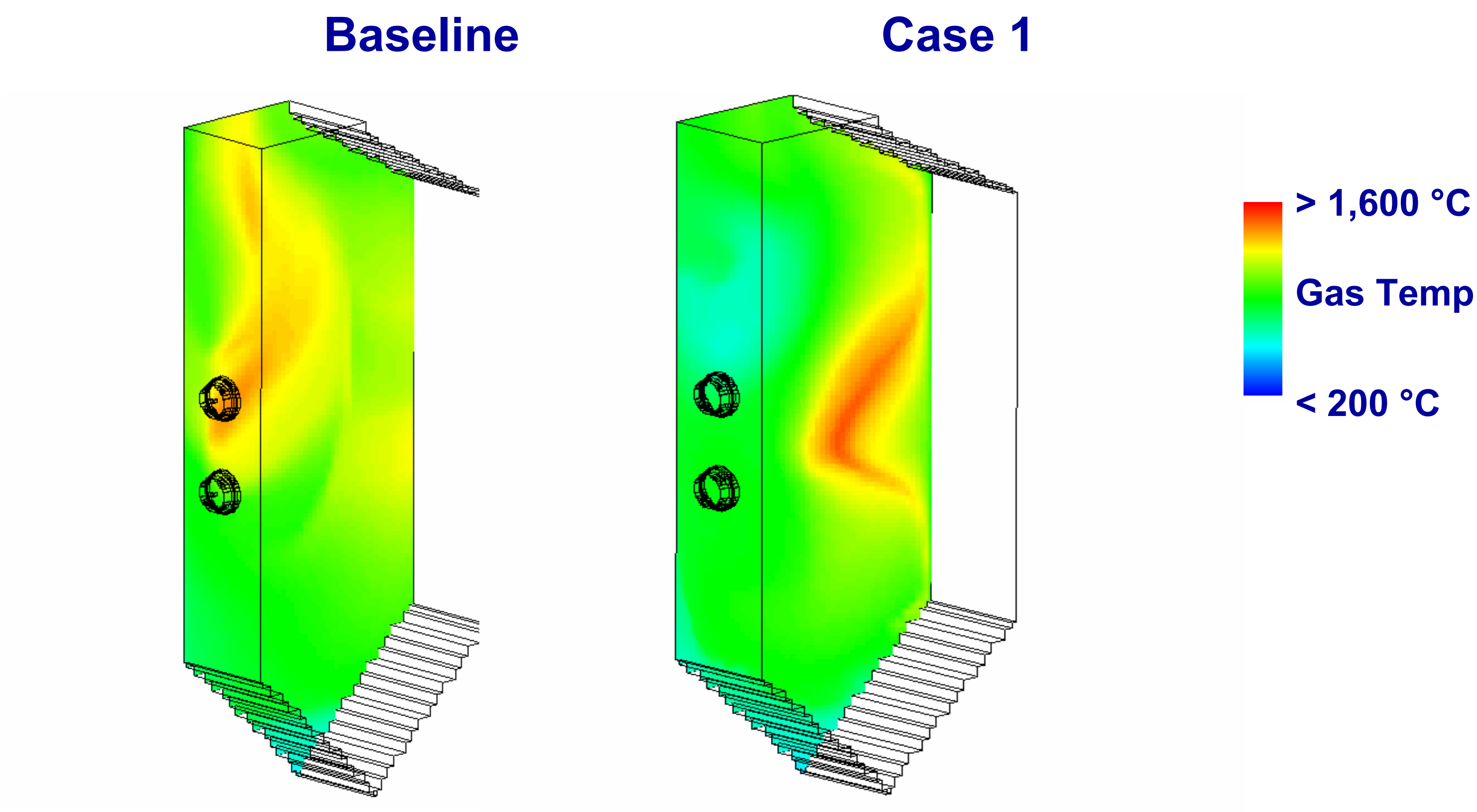
- Baseline Simulation
  - Coal only case
- Syngas co-firing (Case 1)
  - 5% heat input through burners
- Syngas reburning (Cases 2-4)
  - 10% heat input with fuel-lean reburning configuration (SR>1 above burners)
  - 10% heat input with lowered overall stoichiometric ratio
  - 23% heat input with traditional reburning configuration (SR<1 above burners, overfire air)
- Syngas composition change (Case 5)
  - Same operating conditions as Case 3

Baseline & Case 1 Inputs

- Baseline: high swirl burners with no syngas
- Case 1: inject syngas at burner centerline
  - Enhance NH_3 and HCN
  - Add FGR-type dilution effects
  - Need high volume of gas to replace coal
  - Syngas amount limited to 5% by burner size

	Base	case1
Stoichiometric Ratio	1.30	1.30
Exit O_2 %, dry	4.95	4.95
Total Firing Rate, 10^6 BTU/hr	206.6	206.6
Coal		
Feeding Rate, kg/hr	8,180	7,771
Firing Rate, 10^6 BTU/hr	206.6	196.2
Syngas		
Heat Replacement	NA	*5%*
Feeding Rate, kg/hr	NA	2,087
Firing Rate, 10^6 BTU/hr		10.3
Primary Air		
% of Total Air	20.0%	20.0%
Temp, °C	75	75
Flow Rate, kg/sec	5.07	4.95
Secondary Air		
% of Total Air	80.0%	80.0%
Temp, °C	260	260
Flow Rate, kg/sec	20.29	19.81
Overfire Air		
% of Total Air	NA	NA
Temp, °C		
Flow Rate, kg/sec		

Furnace Temperature: Baseline & Case 1

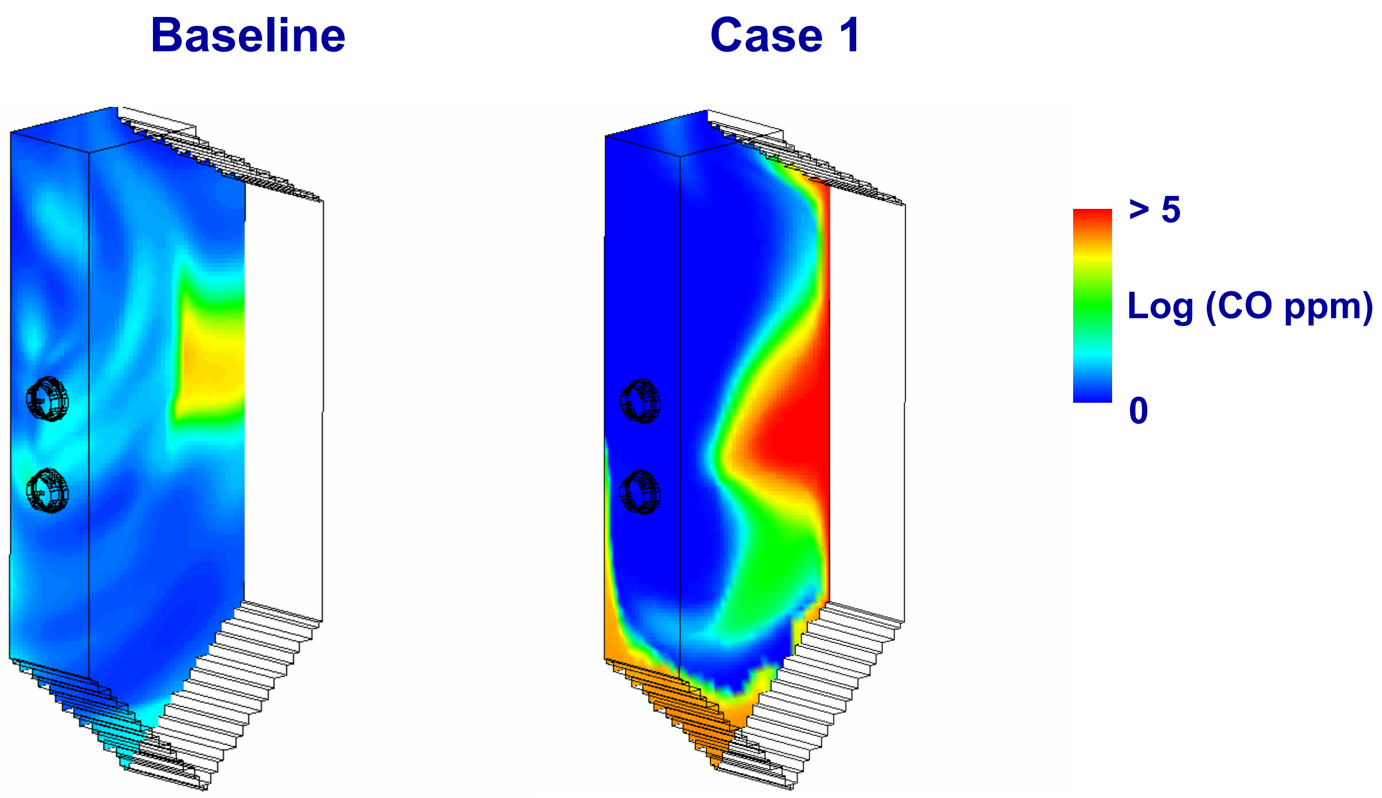


Exit Temp: 1,142 °C

Exit Temp: 1083 °C

- **Case 1 inefficient burner mixing leads to longer flame and lower exit temperature**

CO Concentration: Baseline & Case 1



Exit CO: 3,859 ppm

Exit CO: 16,780 ppm

- Case 1 has much higher CO due to poor mixing

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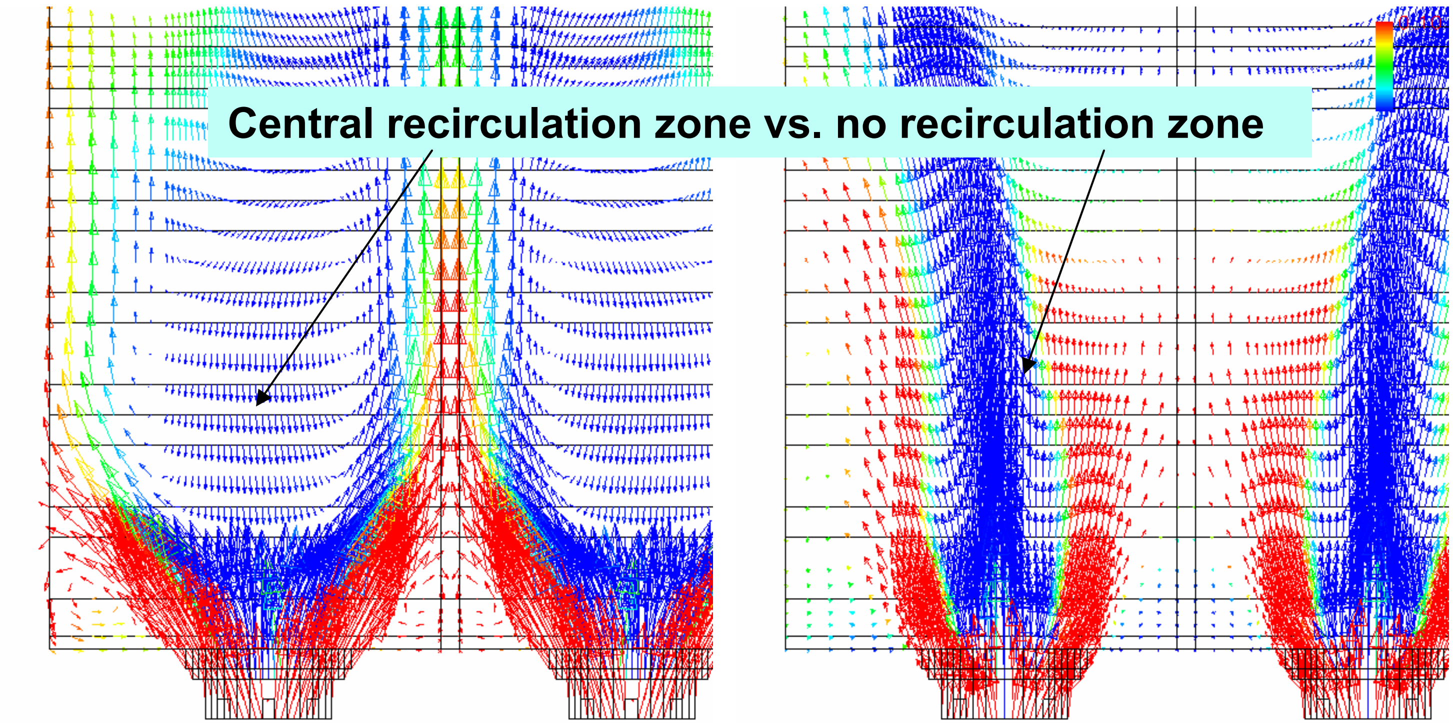
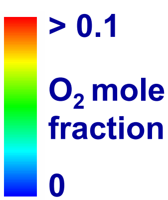
Burner Flow Patterns: Baseline & Case 1

Baseline Bottom Burner | **Case 1 Bottom Burner**



- **High velocity syngas injection eliminates recirculation zone and changes flame shape**



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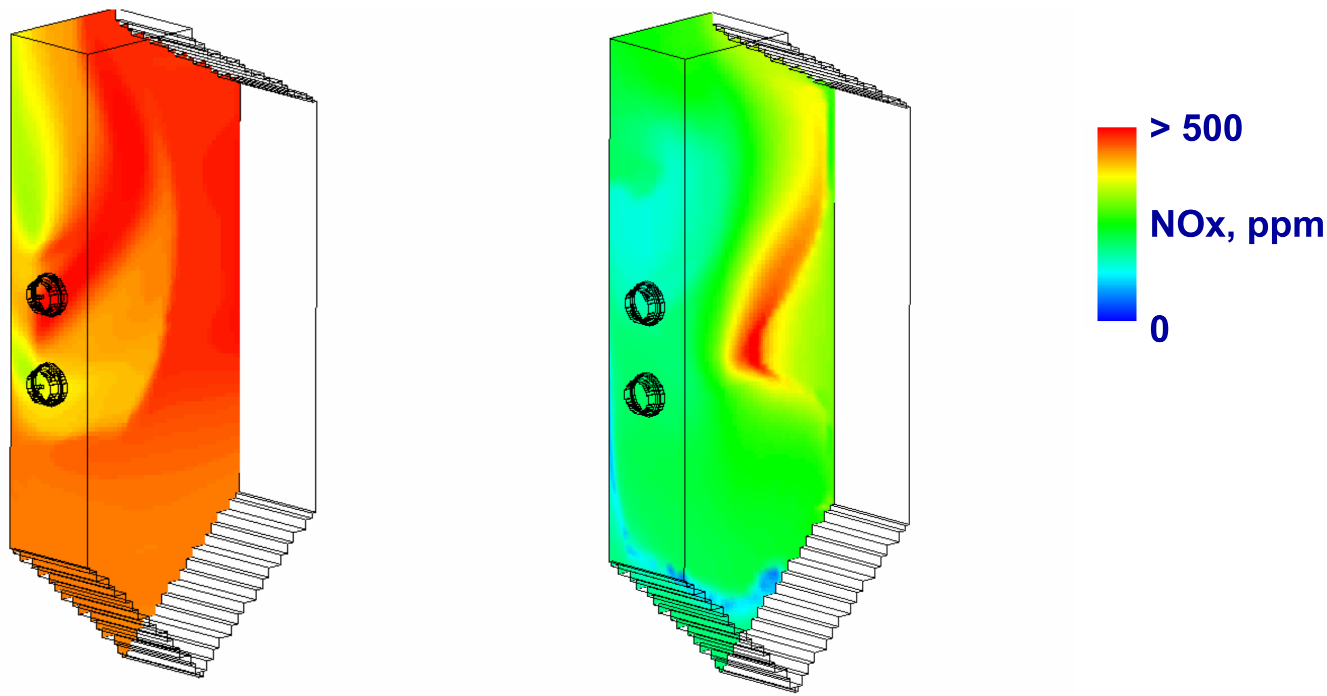
NOx Concentration: Baseline & Case 1

Baseline | **Case 1**

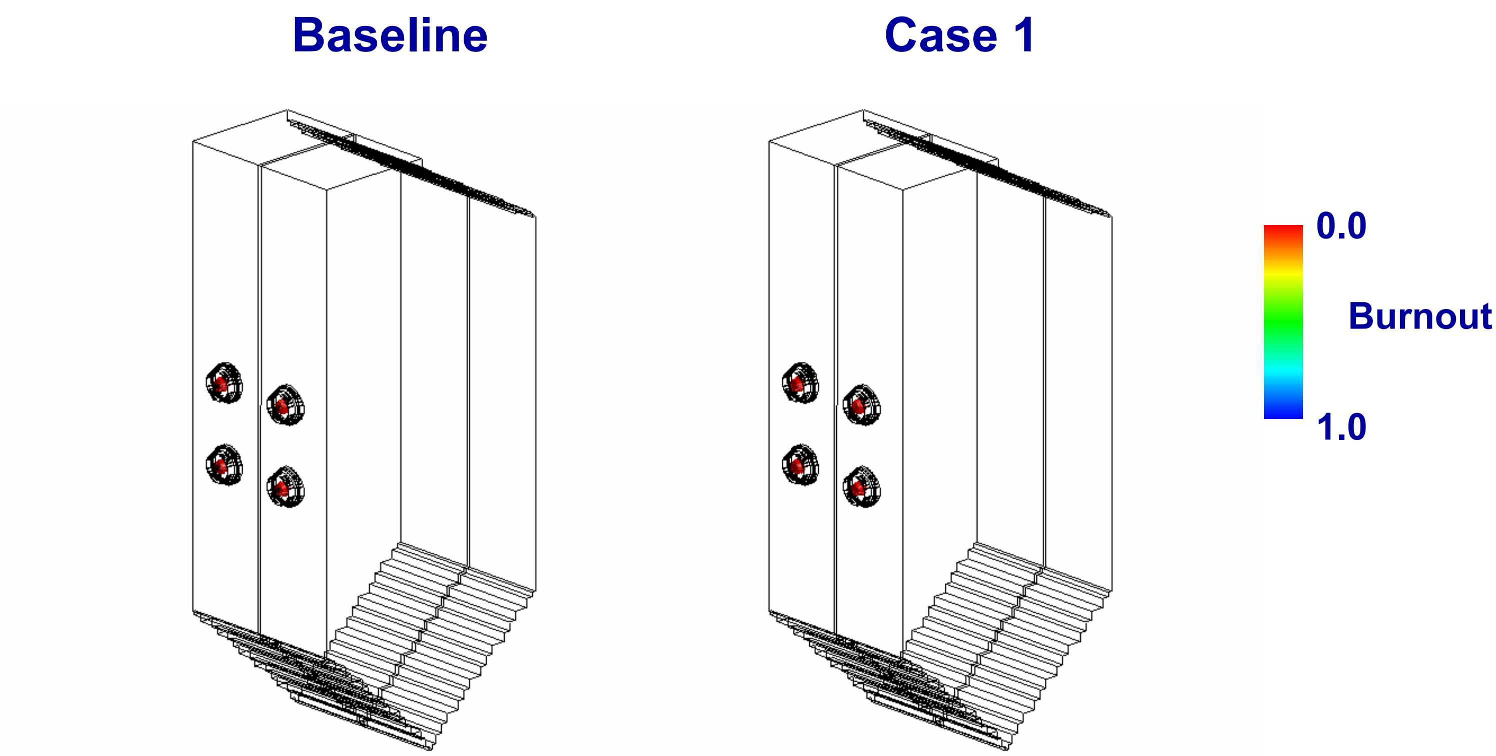


Exit NOx: 460 ppm
@ 6% O2 dry

Exit NOx: 283 ppm
@ 6% O_2 dry

- **Case 1 has much lower NOx formation due to inefficient mixing**

Particle Burnout: Baseline & Case 1

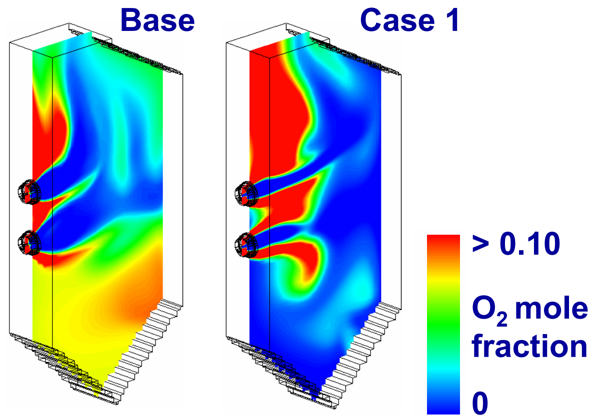


- **Burnout (LOI) depends on: coal reactivity, particle temperature, particle size, oxygen, residence time**
- **Case 1 has more particle deposition on furnace walls**

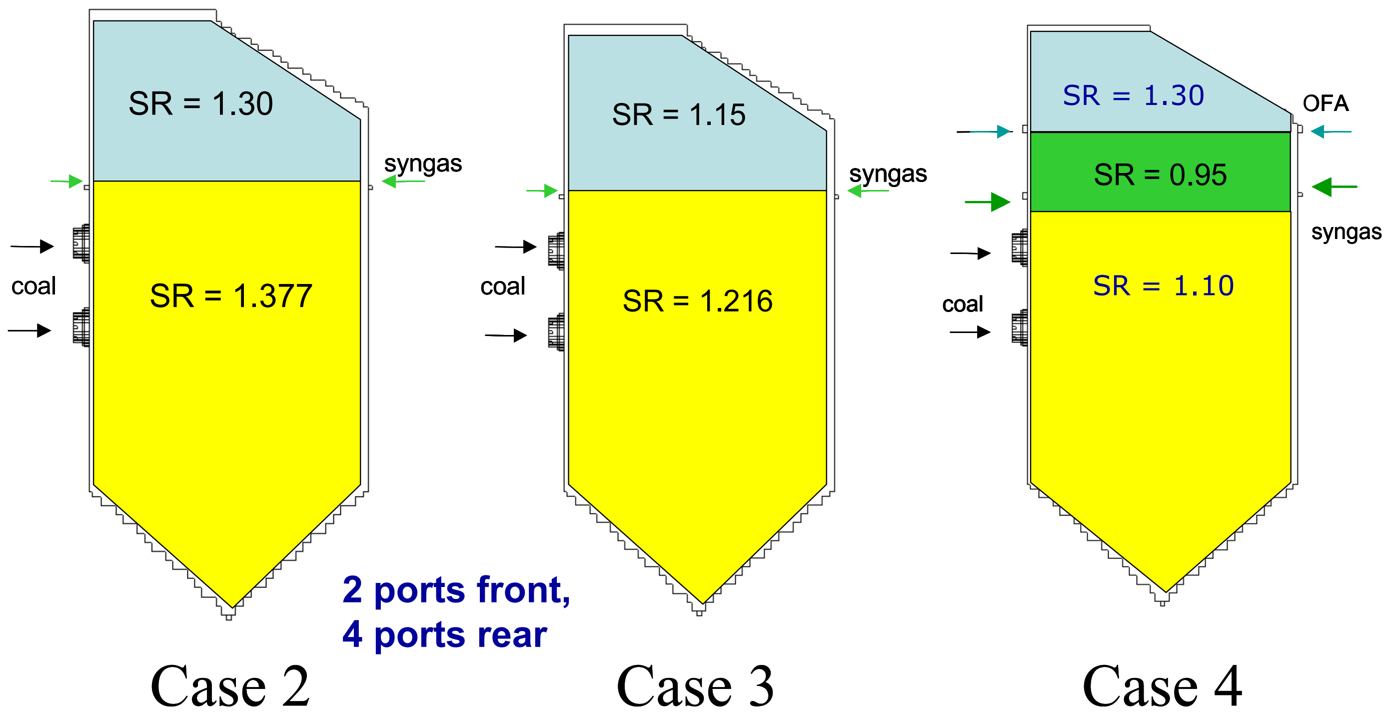
Baseline & Case 1 Summary

- Baseline has typical high swirl/high NOx flames
- Syngas burner injection collapsed burner recirculation zone & changed flame shape
  - Lower NOx
  - Higher CO and LOI (stratified O_2 distribution limits some particles oxygen exposure)
  - Flames/particles could impinge rear wall
- Case 1 not feasible for good combustion

RESULTS	Base	case1
Furnace Exit Temp, °C	1,142	1,083
Furnace Exit CO, dry ppm	3,859	16,780
LOI Total, %	6.5	15.0
Upper Burner Row LOI, %	*11.1*	*22.7*
Lower Burner Row LOI, %	*1*	*3.8*
NOx, 6% Dry, ppm	460	283
% NOx Reduction		38

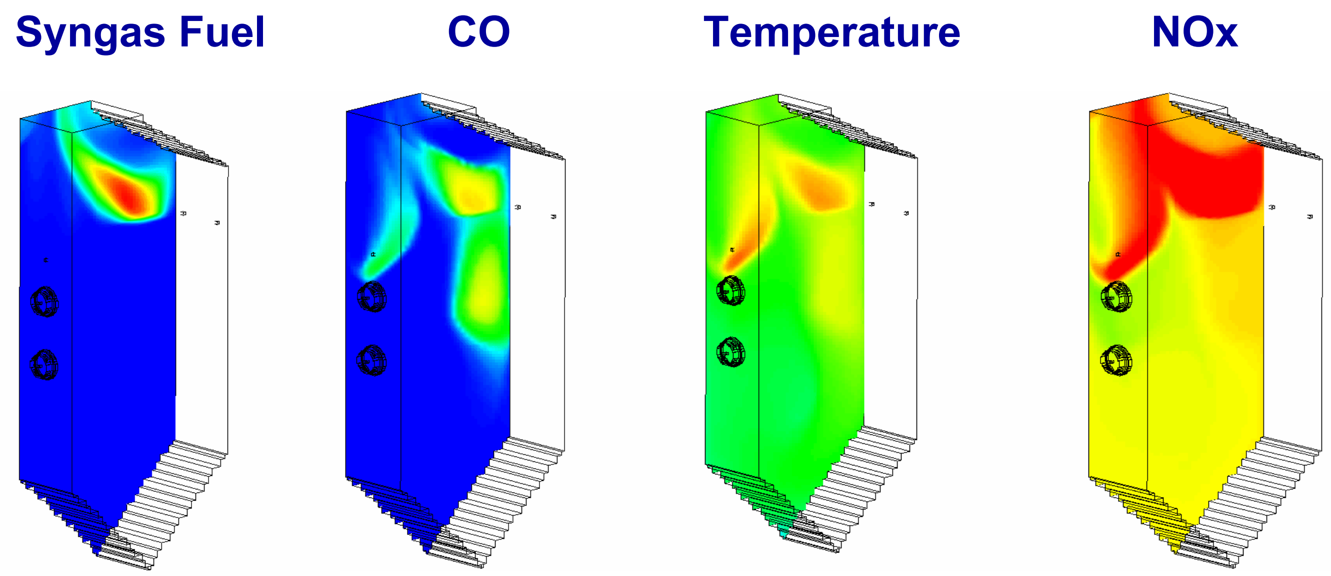


Syngas Reburning



- **Use syngas to replace coal and to create fuel rich regions for NOx reduction (reburning)**
- **Cases 2&3: lean syngas reburning (LSR)**
- **Case 4: traditional (overfire air) reburning**

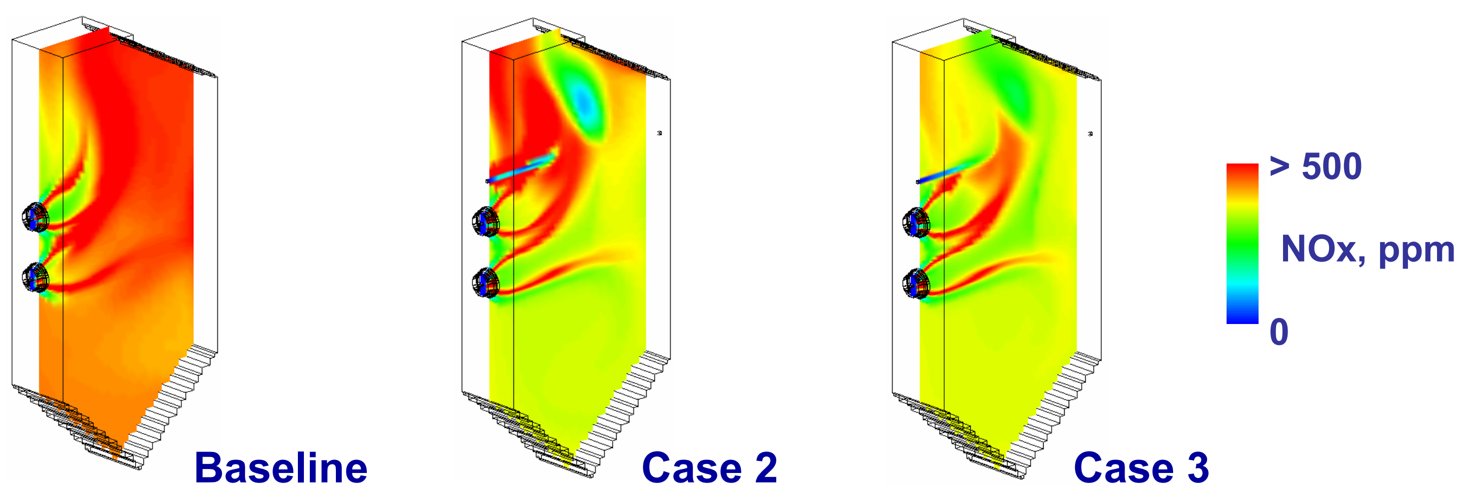
Case 2 Summary
(LSR, 10% syngas, SR=1.30)



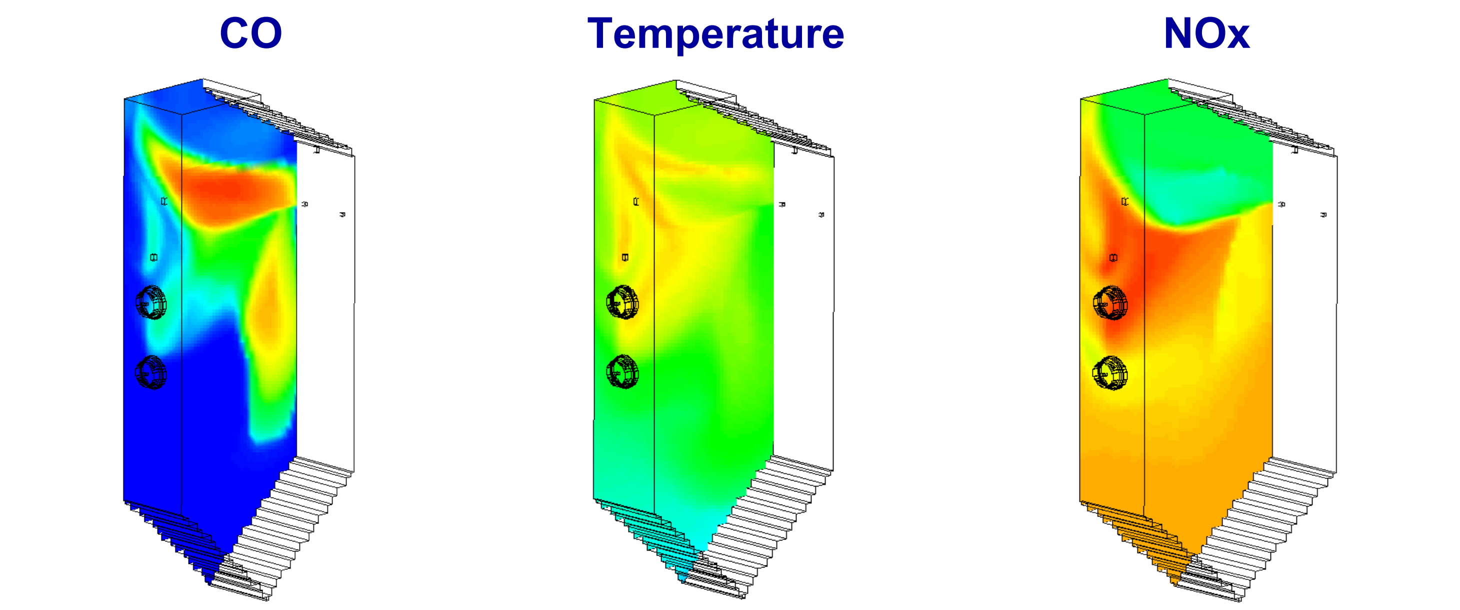
- NOx reduction in upper furnace balanced by higher NOx formation from burners – net 12% reduction
- CO and LOI lower than Baseline due to better mixing and increased burner oxygen

Case 3 Summary
(LSR, 10% syngas, SR=1.15)

- Profiles similar to Case 2
- Lower furnace NOx similar to Case 2
- Lower oxygen produced less NOx in upper furnace and allowed more effective reburning
- Net 30% NOx reduction from Baseline
- Lower oxygen increased furnace exit CO and LOI (nearly triple Case 2)

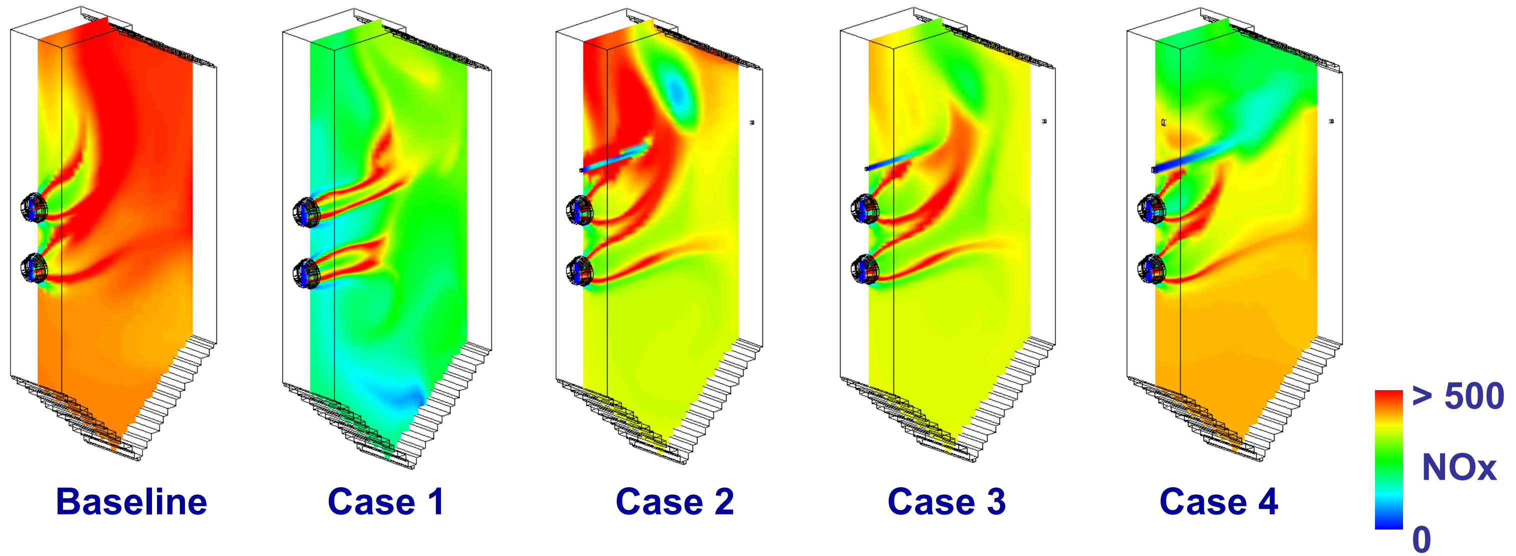


Case 4 Summary
(TR, 23% syngas, 27% OFA, SR=1.30)

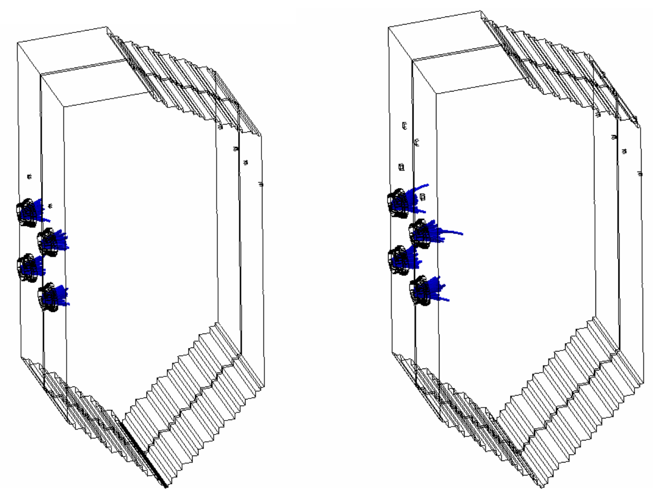


- Increased NOx reduction in reburn zone greater than increased NOx in lower furnace (net 46% reduction)
- Low exit CO due to good OFA mixing
- LOI higher than Baseline and Case 2 due to less oxygen in burner zone and reburn zone

NOx Differences



- NOx impacted by:
  - Burner mixing
  - Burner stoichiometry
  - Furnace flow patterns
  - Syngas quantity & distribution
  - Furnace geometry



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Cases 2-4 Summary

RESULTS	Base	case1	case2	case3	case4
Furnace Exit Temp, °C	1,142	1,083	1,164	1,182	1,201
Furnace Exit CO, dry ppm	3,859	16,780	2,061	6,396	190
LOI, %	6.5	15.0	4.0	11.0	8.6
NOx, 6% Dry, ppm	460	283	406	323	250
% NOx Reduction		38	12	30	46

- **FEGT dependent on heat release elevation and SR change (Case 3)**
- **Exit CO dependent on SR and mixing**
- **LOI dependent on oxygen availability & mixing**
- **Traditional reburning gives best NOx reduction with minimal operational impacts**

Case 5 Summary
(LSR, 10% syngas, SR=1.15)

- Case 5 has same inputs as Case 3 except syngas composition
  - Lower heating value, more NH_3, less HCl
- Case 5 results almost identical to Case 3
- Why doesn't higher syngas NH_3 have a greater impact on NOx?
  - NH_3 concentration from coal flame is higher than from syngas, i.e., coal reactions dominate NOx formation
  - 10% syngas heat input is only ~5% of system mass flow → small changes in syngas composition do not effect syngas performance

Summary

- All reburning designs reduced NOx, but also produced operational impacts
- Lower excess oxygen resulted in lower NOx for lean syngas reburning
- Lowest NOx with traditional reburning design
  - Due to combination of suppressed formation and enhanced reduction above burners
  - Higher CH_i or CO syngas may be difficult to use due to short residence time for CO oxidation
- Performance not impacted by changes in syngas composition
- NOx reductions limited by boiler geometry
- Reburn design and effectiveness are boiler dependent

Additional Information

For more information contact REI at

www.reaction-eng.com